Designation: D6586 – 03 (Reapproved 2021)

Standard Practice for the Prediction of Contaminant Adsorption on GAC in Aqueous Systems Using Rapid Small-Scale Column Tests[1]

This standard is issued under the fixed designation D6586; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers a test method for the evaluation of granular activated carbon (GAC) for the adsorption of soluble pollutants from water. This practice can be used to estimate the operating capacities of virgin and reactivated granular activated carbons. The results obtained from the small-scale column testing can be used to predict the adsorption of target compounds on GAC in a large column or full-scale adsorber application.

1.2 This practice can be applied to all types of water including synthetically contaminated water (prepared by spiking high-purity water with selected contaminants), potable waters, industrial wastewaters, sanitary wastes, and effluent waters.

1.3 This practice is useful for the determination of breakthrough curves for specific contaminants in water, the determination of the lengths of the adsorbates mass transfer zones (MTZ), and the prediction of GAC usage rates for larger scale adsorbers.

1.4 The following safety caveat applies to the procedure section, Section 10, of this practice: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1129 Terminology Relating to Water
D1193 Specification for Reagent Water
D2652 Terminology Relating to Activated Carbon
D2854 Test Method for Apparent Density of Activated Carbon
D2862 Test Method for Particle Size Distribution of Granular Activated Carbon
D2867 Test Methods for Moisture in Activated Carbon

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms in this practice relating to activated carbon, refer to Terminology D2652.

3.1.2 For definitions of terms in this practice relating to water, refer to Terminology D1129.

4. Summary of Practice

4.1 This practice consists of a method for the rapid determination of breakthrough curves and the prediction of GAC usage rates for the removal of soluble contaminants from water. This is accomplished by passing the contaminated water at a constant, controlled rate down flow through a bed of a specially sized granular activated carbon until predetermined levels of breakthrough have occurred.

4.2 When the assumption is made that conditions of constant diffusivity exist within the GAC column, the breakthrough data obtained from the column test can be used to estimate the size and operational conditions for a full-scale carbon adsorber.

5. Significance and Use

5.1 Granular activated carbon (GAC) is commonly used to remove contaminants from water. However if not used properly, GAC can not only be expensive but can at times be ineffective. The development of engineering data for the design

[1] This practice is under the jurisdiction of ASTM Committee D28 on Activated Carbon and is the direct responsibility of Subcommittee D28.02 on Liquid Phase Evaluation.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

of full-scale adsorbers often requires time-consuming and expensive pilot plant studies. This rapid standard practice has been developed to predict adsorption in large-scale adsorbers based upon results from small column testing. In contrast to pilot plant studies, the small-scale column test presented in this practice does not allow for a running evaluation of factors that may affect GAC performance over time. Such factors may include, for example, an increased removal of target compounds by bacterial colonizing GAC[3] or long-term fouling of GAC caused by inorganic compounds or background organic matter.[4] Nevertheless, this practice offers more relevant operational data than isotherm testing without the principal drawbacks of pilot plant studies, namely time and expense; and unlike pilot plant studies, small-scale studies can be performed in a laboratory using water sampled from a remote location.

5.2 This practice known as the rapid small-scale column test (RSSCT) uses empty bed contact time (EBCT) and hydraulic loading to describe the adsorption process. Mean carbon particle diameter is used to scale RSSCT results to predict the performance of a full-scale adsorber.

5.3 This practice can be used to compare the effectiveness of different activated carbons for the removal of contaminants from a common water stream.

6. Summary of Practice

6.1 The development of the RSSCT is based on the dispersed-flow pore surface diffusion model (DFPSDM) (Crittenden, et al.[5]) which takes into account many of the mechanisms that are known to occur in fixed-bed adsorption. The following mechanisms which cause the breakthrough curves for an adsorber to spread out and create the mass transfer zone are included in the DFPSDM: external mass-transfer resistance or film transfer, axial mixing due to dispersion, and the internal mass-transfer resistances of pore and surface diffusion.

6.2 To simulate full-scale performance, the amount of spreading in the breakthrough curve relative to column depth must be identical for the RSSCT and the full-scale column. To achieve this, the relative contributions of the mechanisms that cause most of the spreading are matched by maintaining similarity as the GAC process is scaled. Studies[5] have shown that matching of the spreading of the breakthrough curve can be achieved by equating the dimensionless groups in PFPSDM (Plug Flow Pore Surface Diffusion Model). Under the conditions that intraparticle diffusivities are assumed to be independent of the carbon particle radius, i.e. the condition of constant diffusivity, the following equation describes the relationship between the small and large columns:

$$\frac{EBCT_{sc}}{EBCT_{lc}} = \left(\frac{R_{sc}}{R_{lc}}\right)^2 = \frac{t_{sc}}{t_{lc}} \quad (1)$$

where: $EBCT_{sc}$ and $EBCT_{lc}$ are the empty-bed contact times for the small column (RSSCT) and the large column (full-scale adsorber), respectively; R_{sc} and R_{lc} are the radii of the carbon particles used in the small and large columns, respectively; and t_{sc} and t_{lc} are the elapsed times required to conduct the small- and large-column tests, respectively. The condition of constant diffusivity also requires the Reynolds numbers for the RSSCT and the large column be equal. This means the following equation must also be satisfied:

$$\frac{V_{sc}}{V_{lc}} = \frac{R_{lc}}{R_{rc}} \quad (2)$$

where: V_{sc} and V_{lc} are the hydraulic loadings in the RSSCT and large columns, respectively. Based upon the above equations, the operating conditions for the RSSCT can be selected to precisely simulate the desired (specified) operating conditions for a full-scale adsorber.

NOTE 1—There is an important issue relating to RSSCT design using Eq 2.[6] Sometimes using leads to a design with a high head loss, which increases dramatically with operating time, as the GAC is crushed by a large pressure drop across the RSSCT. This may be avoided by lowering the superficial velocity as long as dispersion does not become the dominant transport mechanism and intraparticle mass transfer is limiting the adsorption rate. The Peclet number based on diameter can be estimated from the following equation:[7]

$Pe_d = 0.334 \; for \; 160 \leq Re \cdot Sc \leq 40{,}000$

When the velocity is reduced below what is given in Equation A, axial dispersion, which is caused by molecular diffusion, can be more important in the RSSCT than in the full-scale process. Consequently, Equation A can be used to check whether dispersion becomes important as the velocity of the RSSCT is reduced in an effort to reduce the head loss. Typical Sc values for SOCs is ~2000; consequently, the Re for the RSSCT must be kept greater than ~0.1 and the Pe must be kept above 50 for the length of the mass transfer zone.

NOTE 2—Empty-bed contact time (EBCT) is defined as the bed volume (in liters) divided by the water flow rate in liters/minute. For example if a full-scale adsorber holds 20 000 L of activated carbon and the water flow rate is 2500 L/min, the EBCT would be equal to 20 000/2500 or 8.0 min.

6.3 The assumption that conditions of constant diffusivity exist within the GAC column does not apply to all waters or all target compounds. For example this assumption does not apply for the decolorization of water and the adsorption of large molecules, such as humic and fulvic acids. It is recommended that at least one RSSCT pilot-column comparison be conducted to aid in selecting the RSSCT design variables for a given water matrix (Crittenden, et al.).[5] A detailed comparison between the constant diffusivity and proportional diffusivity approaches and their respective domains of application is beyond the scope of this practice.

6.4 GAC bed volume and preparation methods are important design parameters for the RSSCT. The GAC bed volume used will determine the required water pumping rate and affect the amount of water needed to complete the test. The minimum

[3] Owen, D. M., Chowdhury, Z. K., Summers, R. S., Hooper, S. M., and Solarik, G., "Determination of Technology and Costs for GAC Treatment Using the ICR Methodology," AWWA GAC & Membrane Workshop, March 1996, Cincinnati, OH.

[4] Knappe, D., Snoeyink, V., Roche, P., Prados, M., and Bourbigot, M., "The Effect of Preloading on RSSCT Predictions of Atrazine Removal by GAC Adsorbers," *Water Research*, Vol 31, No.11, 1997, pp. 2899–2909.

[5] Crittenden, J. C., Berrigan, Jr., J. K., and Hand, D. W., "Design of Rapid Small-Scale Adsorption Tests for a Constant Surface Diffusivity," *Journal Water Pollution Control Federation*, Vol 58, No. 4, 1986, pp. 312–319.

[6] Crittenden, J. C., Berrigan, Jr., J. K., Hand, D. W., and Lykins, Jr., B. W., "Design of Rapid Fixed-Bed Adsorption Tests for Non-Constant Diffusivities," *Journal of Environmental Engineering*, Vol 113, No. 2, 1987, pp. 243–259.

[7] Fried, J. J., *Groundwater Pollution*, Elsevier Scientific, Amsterdam, The Netherlands, 1975.